Active magnetic shield for biomagnetic measurements

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1 Introduction

Biomagnetic measurements are sometimes disturbed by the environmental magnetic noises originating from movement of trains [1] or of cars [2] or from geomagnetic activity [3]. Up to this time, magnetic shielded room (MSR) with materials of high permeability is used to shield magnetic noises, however, for MSR alone, it is insufficient to eliminate environmental noises at lower frequency than 1 Hz.

Thus a variety of active field compensation system has been developed to improve the shielding effect at the low frequency fields, [4-9].

We propose a novel magnetic field compensation system, which improves the performance of a MSR. In this paper, the new system was introduced to a low performance MSR in Sophia University which suffers environmental urban noises.

2. Method

2.1 Compensation system

Fig.1 shows a schematic diagram of the magnetic compensations system, and Fig.2, an appearance of it. The magnetic field compensation system is composed of six high resolution magnetic sensors and of six current coils fed by controllers compensating the external magnetic fields. The six sensors are positioned at the center of the six wall surfaces of the MSR respectively.

The acquired magnetic field signals by the six sensors are processed and determine coil currents so as to minimize the fluctuation of magnetic field at the center of the MSR.

The MSR has a size of 2,000 mm × 1,300 mm × 2,050 mm and is composed of 2 - layered Mumetal (inner layer: 1 mm, outer layer: 1 mm) and 1 - layered copper (70 µm).

The MSR itself has low shielding performance of 30 dB at 1.0 Hz and 50 dB at 50 Hz as shown in Fig.3. The shielding effects, at low frequency below 1.0 Hz, were insufficient to apply the MSR to a biomagnetic measurement.

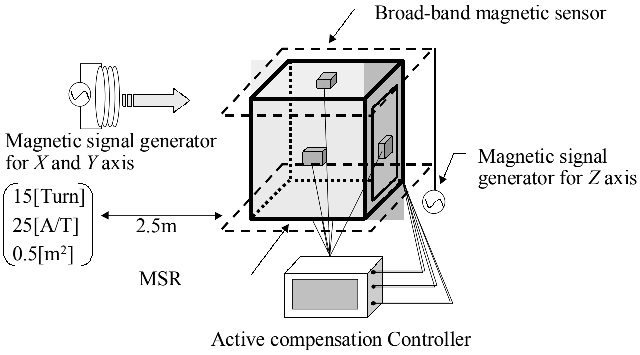
Broad-band magnetic sensor
Magnetic signal generator for X and Y axis
15[Turn]
25[A/T]
0.5[m^2]
2.5m
MSR
Magnetic signal generator for Z axis
Active compensation Controller

Figure 1: *Schematic diagram of the system. The magnetic field compensation system is composed of six high resolution magnetic sensors and of six current coils fed by controllers.*

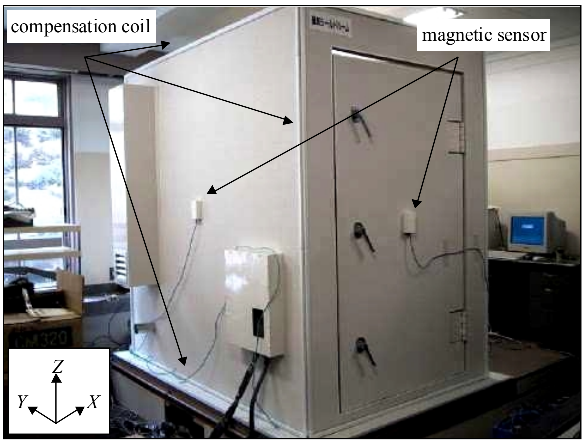

Figure 2: *Appearance of the compensation system applied to MSR in Sophia University. Each sensor is positioned at the center of each wall surface of the MSR respectively.*

2.2 Measurements

Shielding effects are evaluated by another magnetic sensor (Applied physics system, APS520A) positioned at the center of the MSR using magnetic signal generators having 175 Am^2 dipole moment located about 2.5 meters distant from the MSR for *X* and *Y* axes (Fig.1). For *Z* axis, two one-turn coils are surrounding the ceiling and the floor wall of the MSR, respectively, and the coils are connected in series to generate a homogeneous magnetic field signals (Fig.1). Magnetic signals have a rectangular wave shape and the frequencies are 1.0 Hz for all axes.

Shielding effects were measured for environmental magnetic noises, as well as for magnetic signals of *Z* axis.

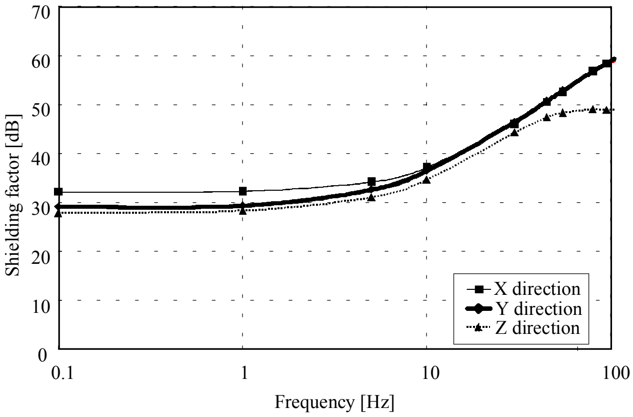

Fig.3 Frequency dependence of shielding effects of the MSR in Sophia University.

3 Results

Fig.4 shows frequency spectrum of field components *X*, *Y*, *Z* of the magnetic signals when imitated 1.0 Hz magnetic noises by the generator were applied. In Fig.4, "on" (lower spectrum graph) stands for the spectrum in case of functioning the system, and "off" (upper spectrum graph) stands for the spectrum in case of not functioning the system. In comparison of the spectrum "on" with the spectrum "off", we determine the supplementary shielding effects by the system as 41.7 dB for *X* axis, 25.9 dB for *Y* axis and 36.0 dB for *Z* axis at 1.0 Hz, and the shielding effects cover frequencies from dc to 50 Hz.

Fig.5 shows a typical time chart of vertical (*Z* direction) component of environmental magnetic field in MSR where "on" followed by "off", which clearly demonstrates the supplementary shielding effects.

Fig.6 shows frequency spectrum of the environmental magnetic noises comparing "on" with "off", which suggest the supplementary shielding effect as 21.9 dB for the environmental magnetic noises.

4 Discussion

We obtained an active magnetic field compensation system whose shielding performance covers from DC to 50Hz and has attenuation of more than 25 dB from dc to 1 Hz.

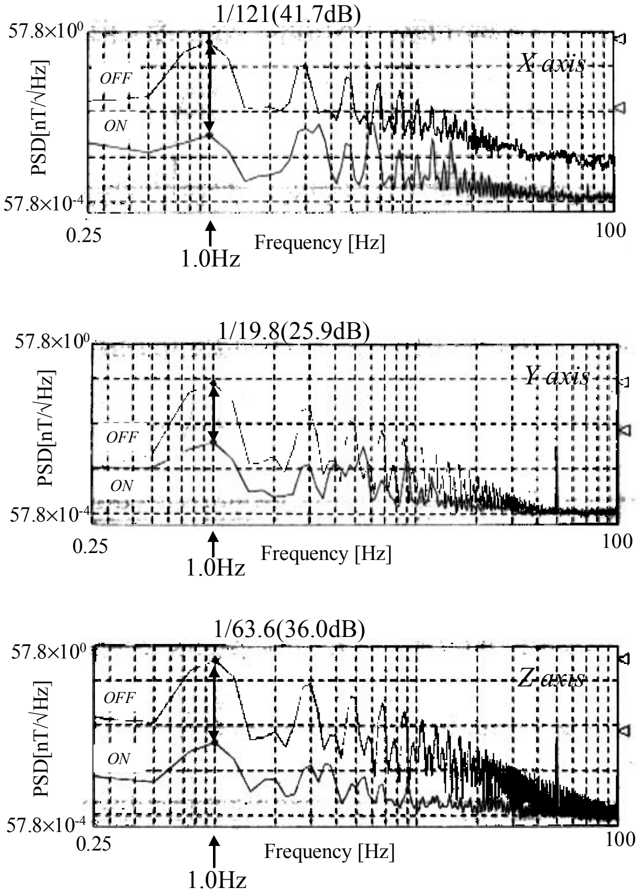

Figure 4: *Frequency spectrum of magnetic signals of a magnetic sensor in the center of the MSR induced by magnetic field of 1.0 Hz. First row figure stands for X direction, second row, Y and third row, Z.*

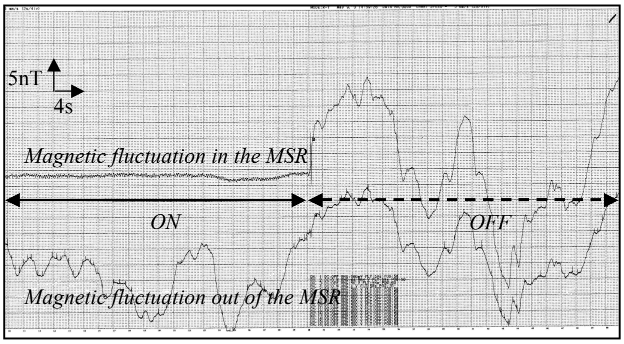

Figure 5: *Time chart of vertical (Z direction) component of environmental magnetic field in MSR where "on" followed by "off".*

The principle of an active magnetic field compensation system is to cancel an external magnetic noise field by an artificial magnetic field formed by compensation coils. It is most important, for canceling the external field, to determine the external field by sensors being usually put at different positions than where we want to cancel the field.

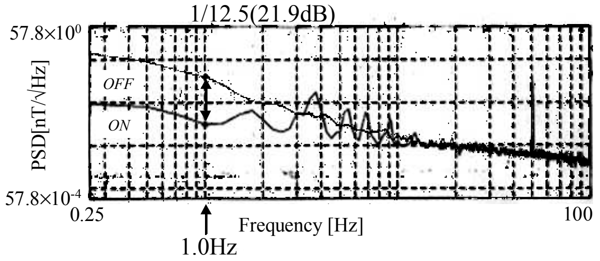

Figure 6*: Frequency spectrum of environmental magnetic noises in the MSR comparing functioning (on) and not functioning (off).*

Therefore the ideal position of the sensors is the place where we want to cancel the field, however, it is not possible to locate the sensors at the place because of the feedback response or of the internal noises of the sensors.

We may view that a MSR compensates an external magnetic field by magnetizing itself, introducing a compensating field inside of it. The cancel coils of the active magnetic field compensation system give the MSR additional magnetization to compensate the external field more precisely. In practice, minimizing the field signal of another sensor located at the place we want to cancel the field, we obtain the best compensating field .by adjusting the ratio of coils current with the output of the sensors.

However, the magnetization of MSR depends on the magnetic field distribution and its frequency, in other words, the magnetization by the external magnetic field is different from that by cancel coils.

Therefore, even though we obtain the best compensating field by adjusting the ratio at a frequency, at the other frequencies or at the other noise source, the adjustment does not keep the best compensating field.

If we want to obtain better compensating system we need to detect the difference of the magnetization between the external field and the coils field. We detect the difference by locating sensors at the surface of the MSR and try to keep the best compensating field by compensating the difference.

This gives the wide band shielding performance.

However, the maximum frequency of effective shielding was 50Hz and there are difference among the axes. These may be due to non-symmetry of the MSR like aperture of doors of the MSR for *Y* axis, or magnetic materials in the floor of the room where the MSR is setting for *Z* axis, for example, steel bars and frames in a ferroconcrete building.

The shielding effect for environmental noises in fig.6 is different from that for magnetic signal in fig.4 for *Z* axis. This may be resulted from the difference of magnetic field distributions between the environmental and the magnetic signals.

5. Conclusion

We demonstrated that a system combining an active magnetic field compensation system with a low performance MSR brings field attenuation of more than 55 dB at very low frequencies which give a low price and low weight shielding system having a sufficient noise reduction for biomagnetic measurements.

References

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